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Protein Content of Winter Wheat Grain as Related to Soil and Climatic Factors in the Semiarid Central Great Plains[1]

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ABSTRACT

Protein content of wheat (*Triticum aestivum* L.) grain has decreased in recent years in the Central Great Plains. Conflicting reports concerning the causes for this decrease prompted this investigation. Protein content data from North Platte, Neb.; Akron, Colo.; and several southwestern Nebraska locations were shown to be negatively correlated by linear regression with total precipitation >1.25 cm for a 15-day period 40 to 55 days before maturity ($r = -0.70^{**}$) or with available soil water at seeding to a depth of 1.2 or 1.8 m ($r = -0.79^{**}$). Grain protein levels were shown to be positively correlated by linear regression with total soil NO_3-N to depths of 1.2- or 1.8-m ($r = 0.82^{**}$) and by curvilinear regression with maximum air temperature for a 5-day period 15 to 20 days before maturity ($R = 0.74^{**}$). With all four factors combined, $R^2 = 0.96$. With available soil water at seeding plus NO_3-N in the soil profile at seeding and protein content of wheat grain, $R^2 = 0.86$. Maximum yield was obtained with 28 cm of soil water available at seeding, and at least 106 kg/ha of NO_3-N at seeding was needed to obtain grain with 12% protein.

Additional index words: **Rain, Maximum air temperature, Soil water, Soil NO_3-N.**

PROTEIN content of wheat (*Triticum aestivum* L.) grain has been studied for more than 100 years (14). Although such studies have provided many insights into factors that affect protein content of wheat, contradictions between recent reports (8, 21) indicate that the effects of these factors are not clearly understood. Previous investigators have shown protein content of wheat to be the product of the integrated interrelations of soil fertility, climate and wheat variety during growth of the wheat plant (16). Nevertheless, under identical soil and climatic conditions, differences in wheat varieties had little effect (21) on protein content of wheat grain. Therefore, in this study varietal characteristics influencing yield potential and N uptake potential will not be considered as major factors influencing protein content of grain.

Protein is the principal nitrogen-containing constituent in the wheat kernel. Therefore, soil and climatic factors that affect the N nutrition of the wheat plant will cause differences in wheat grain protein content. Wheat protein levels below the 11.5% minimum acceptable for milling for bread flour (11) are being reported in western Kansas (20) and western Nebraska (15). The objectives of the investigation reported here were to: (i) identify some of the major soil and climatic factors influencing protein content of hard red winter wheat grain and (ii) determine the interrelations of these factors as they affect production and quality of wheat.

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METHODS AND MATERIALS

Protein content of wheat grain was correlated with available soil water in a 1.2- or 1.8-m profile, total NO_3-N in a 1.2- or 1.8-m profile, soil temperature at the crown depth of the wheat plant, daily growing period rainfall >1.25 cm, and daily maximum air temperature (Table 1). All possible days and number of consecutive days starting and ending on all possible days during the 135-day spring growing period for the number of crop years available at each location were used in determining the extent of correlation of protein content of wheat grain with rainfall and maximum air temperature. The extent of multiple correlation of rainfall, soil water, soil NO_3-N, and maximum air temperatures in all combinations, except maximum air temperature, from off-station locations was also evaluated using the number of crop years of data from each location represented by the factor with the smallest number of crop years for each particular factor and location. The crop years of data available for each factor from North Platte, Nebr.; Akron, Colo.; and southwestern Nebraska off-station locations are presented in Table 1. The soils on which these 55 crops were grown included: silt loam 50 years, loam 2 years, and loamy sand, very fine sandy loam, and fine sandy loam each 1 year.

Soil temperature data from North Platte were obtained from greenhouse and growth chamber studies with controlled soil temperatures, and 14 crop years of field measurements. Soil temperature was measured with thermocouples placed at the crown depth of the plants. The thermocouples were hooked to a strip charter recorder and in the field, temperature was recorded in each treatment once each hour every other day from growth initiation in the spring to soft dough growth stage. Under controlled conditions, measurements were made hourly every day from growth initiation to heading. The daily value

Table 1. Crop period used and number of crop years of data available at each location for each factor.

Location	Period of years used	Available soil water at seeding	NO_3-N in soil profile at seeding	Precipitation 44-55 days before maturity	Max air temp. 15-20 days before maturity	Soil temp. at crown depth
		Number of years				
North Platte, Nebr.	1949-70	14	14	21	21	22
Akron, Colorado	1955-70	18	18	18	18	--
SW Nebraska*	1966-69	16	16	16	--	--
Total		48	48	55	39	22

* Data obtained from literature citations 2, 3, and 4.

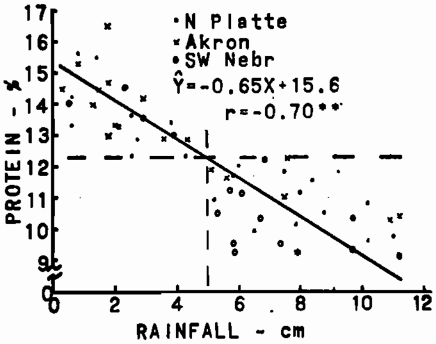

Fig. 1. Wheat grain protein as related to rainfall received between 40 to 55 days before maturity (all locations).

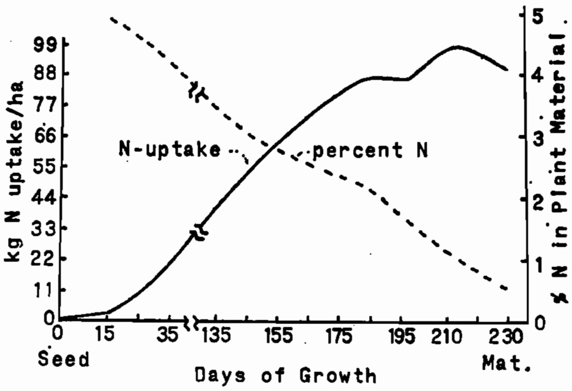

Fig. 2. Total N uptake and percent N in plant material from seeding to maturity of wheat grown in the field at North Platte, Neb. (9-year average).

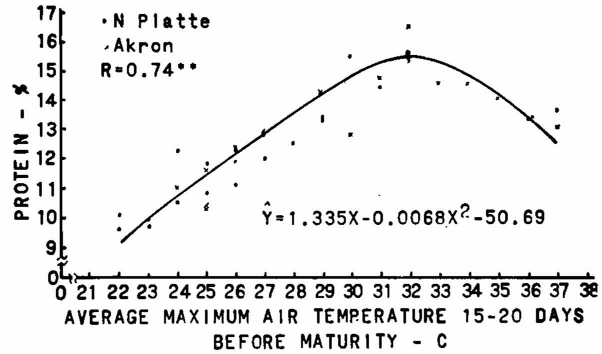

Fig. 3. Wheat grain protein as related to average maximum air temperature for a 5 day period, 15 to 20 days before maturity, at North Platte, Neb. and Akron, Colo.

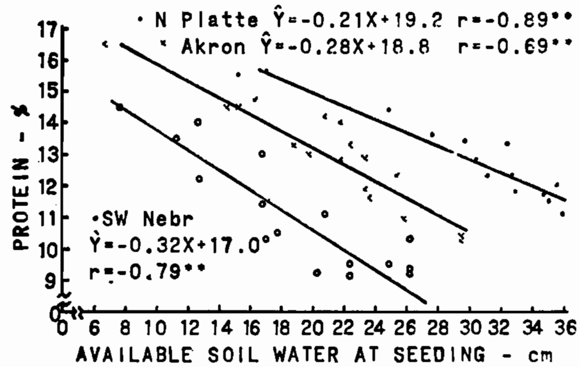

Fig. 4. Wheat grain protein as related to available soil water at seeding (all locations).

used was an average of the 24 recorded values for each day. All other data were collected from field experiments. Protein content of the grain reported is the product of the factor 5.7 times the percent total N in the grain as determined by the Kjeldahl procedure. Available soil water was determined by subtracting the minimum point of exhaustion from total soil water. Rainfall and maximum air temperatures were obtained from measurements made at or near the sites where the wheat was grown. Air temperatures were not available for the off-station locations. None of the wheat at any location received N fertilizer at any time.

RESULTS AND DISCUSSION

Precipitation received during a 15-day period 40 to 55 days before maturity of the grain had the greatest influence on protein content of the grain (r = —0.70* Fig. 1). During these 15 days when the wheat plant was developing from early boot growth stage to where the awns of the first head were visible [stage 8.5 to 10.1 Feekes scale, (10)], each 1.25 cm of precipitation received decreased protein content an average of 0.75% for all locations (Fig. 1). During the 55 crop years represented by all locations, protein contents never exceeded 12.3% when more than 4.8 cm of rainfall was received during this 15-day period. Rainfall during this period: (i) occurs after the wheat plant has taken up nearly 90% of its total amount of N (Fig. 2) and (ii) increases the percentage of tillers that produce heads (Table 2). Therefore, a dilution of N is believed to occur because there are a greater number of heads to which the N within the plant must be translocated.

Maximum air temperature had the greatest effect on grain protein during the 5-day period, 15 to 20 days before maturity (R = 0.74** Fig. 3). The plants during these 5 days develop from soft dough to hard dough growth stage (growth stage 11.2 to 11.3 Feekes scale). The relationship was curvilinear, with protein increasing up to 32 C and decreasing thereafter (Fig. 3). Maximum air temperatures greater than 32 C during the last 15 days of growth has been reported to decrease protein content of wheat flour (5). Thus, maximum air temperatures above 32 C during the last 2 to 3 weeks before maturity are detrimental to wheat grain protein content.

Available soil water at seeding was negatively related to protein content at all locations (Fig. 4). Correlation coefficients (r) were —0.89**, —0.69*, and —0.79** for North Platte, Akron, and southwestern Nebraska, respectively. Protein levels varied with locations owing to the different soil water levels. Protein decreased 0.45, 0.80, and 0.75% per 2.5-cm increase in available water present at seeding for North

Table 2. Year, rainfall 40 to 55 days before maturity and the percent of tillers that produce heads on wheat growing in the field at North Platte, Neb.

Year	Rainfall	Heading tillers
	cm	%
1963	0.6	54
1965	11.6	99
1966	5.9	88
1967	2.4	37
1969	4.0	72
1970	1.5	46
	r = 0.874**	

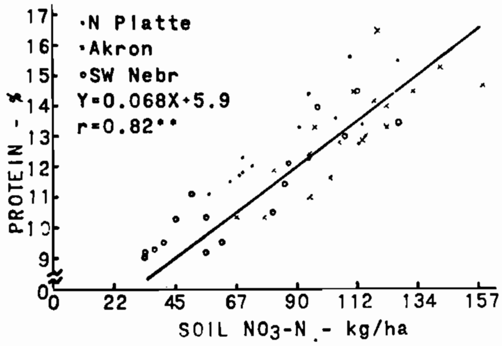

Fig. 5. Wheat grain protein as related to soil NO_3-N in the profile at seeding (all locations).

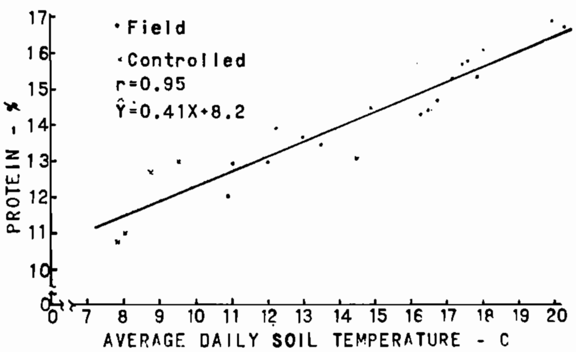

Fig. 6. Wheat grain protein as related to average daily soil temperature at the crown depth from spring growth initiation to soft dough at North Platte, Neb.

Platte, Akron, and southwestern Nebraska, respectively. Protein decrease associated with increasing amounts of available soil water at seeding has been previously reported as due to grain yield increases (21). Forty percent of the water used by an average wheat crop in the semiarid Central Great Plains comes from the soil; therefore, a soil water increase generally increases yield (6), but protein does not necessarily decrease when yields increase (8).

Protein decrease associated with higher quantities of soil water may be due to: (i) depth of soil water storage; (ii) location of NO_3-N in the soil profile; and (iii) soil water use pattern of wheat. Under dryland conditions in the semiarid Great Plains much of the stored soil water is below the 61-cm depth (6). Conversely, most of the soil NO_3-N accumulation during fallow is above the 61-cm depth (18). Winter wheat develops roots below 61 cm largely after growth initiation in the spring and, except for the surface 10 cm, few roots grow above the 61-cm depth after spring growth initiation (9). Shortly after breaking dormancy in the spring, growth is rapid (Fig. 2) and often with little precipitation (17) to rewet the surface soil. Wheat uses water from deeper soil depths only when water nearer the soil surface has been depleted (12); therefore, growth after the soil water and NO_3-N above 61 cm has been exhausted will occur with soil water below 61 cm where little N is available for uptake. When this takes place, the deeper soil water would be available for increasing grain yield, but limited plant uptake of N during this rapid growth period

Table 3. Release of N from Weld silt loam having different total N contents in the 0- to 5-cm depth, Akron, Colo.

Soil analysis	
Total N, %	Nitrifiable N,* kg/ha
0.109	63
0.097	58
0.094	56
0.087	53
0.084	48

* Incubated 6 weeks at 30C and field capacity moisture.

would lower total N content of the plants and grain protein levels would be reduced.

Soil nitrate in the profile at seeding with all locations combined was positively correlated with grain protein content ($r = 0.82^{**}$ Fig. 5). Protein increased an average of 0.15% for each kg/ha of NO_3-N in the soil at seeding. In general, the NO_3-N in semiarid Central Great Plains soils at seeding is that NO_3-N released through mineralization during the preceding fallow as each wheat crop generally uses all NO_3-N in the soil leaving little or no carry-over from one crop to the next. Where the nitrate-furnishing power of soils is related to the total N level of the soil (Table 3) and the total N level has been reduced by erosion, many years of cropping without fertilizer N, or other factors (13), the NO_3-N released during fallow may not be sufficient to produce grain with high protein. Thus N fertilization may become necessary on these soils to produce wheat grain with an acceptable protein level.

Average soil temperature at the crown depth of wheat between growth initiation in the spring and soft dough growth stage was highly correlated with protein of the grain at North Platte (Fig. 6). Increasing the soil temperature from 8 to 20 C increased protein of the grain an average of 0.4% for each degree increase. Increasing the average soil temperature at the crown depth of wheat during this growth period increased N uptake (19). Thus, cooler soil temperatures decrease grain protein content because of reduced N uptake. Differences in protein content of wheat due to temperature differences may account for slightly higher protein content in wheat grown on bare than on stubble-mulched soil in some years (18). Mulches tend to reduce soil temperature during the spring growth period and hence, reduce N uptake (19).

Multiple correlation of any two of the four factors (soil water, soil NO_3-N, rainfall, and maximum air temperature) with protein content improved the relationships. The extent depended on the factors used. Available soil water at seeding time and soil NO_3-N in the profile at seeding time had the highest relationship with protein content ($R = 0.93^{**}$). Including a third factor of either precipitation 40 to 55 days before maturity or maximum air temperature 15 to 20 days before maturity improved the relationship somewhat. When all four factors were available and combined, however, the best relation was obtained ($R = 0.98^{**}$).

As shown earlier, protein decreased when soil water content increased, whereas protein increased when soil NO_3-N increased. Thus, an interaction of these two factors is apparent. The numerical product of these two factors produce an index that when plotted against protein and the associated range of grain yields (Fig. 7) explains (i) why a high relation between yield and protein was not obtained and (ii) why some

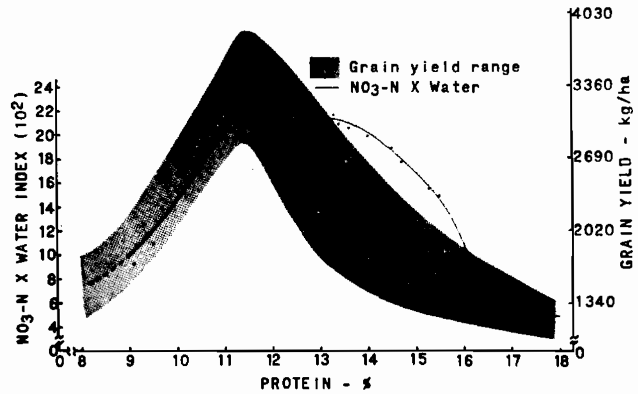

Fig. 7. The available soil water at seeding times soil NO_3-N in the profile at seeding index as related to the protein content of wheat grain and associated range of grain yield.

investigators have reported positive yield-protein relations (8) while others have reported negative relations (21).

The soil water at seeding $\times$ soil NO_3-N at seeding index produced a reasonably accurate prediction for protein content of grain at all soil water and soil NO_3-N levels studied. The range of associated grain yields is wide, however, especially when protein contents were between 12.5 and 15.5%. With protein levels between 9 and 11.5% soil NO_3-N was limiting both protein content and yield. Protein contents > 12.0% were obtained with increasing amount of NO_3-N in the soil and decreasing amount of available water in the soil. Thus limiting water affected only yield, whereas limiting NO_3-N affected both yield and protein. Highest soil NO_3-N $\times$ soil water index was obtained with 95 kg/ha of N and 25 cm of available soil water and produced wheat grain with 12% protein. Highest grain yield obtained was with 78 kg/ha of N and 28 cm of available soil water, but grain protein level was only 11.5%. Therefore, with the 28 cm of soil water available, at least 106 kg/ha of NO_3-N would have been needed to produce grain with 12% protein at the highest yield level. In most years this soil water level can be obtained with good stubble mulch fallow practices, but N fertilizer may be frequently required to obtain the N level needed.

Data from Colby, Kansas (7), not used in determining the relationship in this paper, fit directly on the curve in Fig. 7. Therefore, it is believed that Fig. 7 should be reasonably applicable to most of the semiarid Central Great Plains. Modification to fit conditions in other areas may be feasible.

Relationship of protein content to other factors including average daily air temperatures, daily minimum air temperatures, daily open pan evaporation, available soil water in the spring, yield, test weight, and percent yellowberry were all studied. None of these factors showed any significant relation to protein content except the incidence of yellowberry. For each 10% increase in yellowberry, protein decreased linearly 0.4%. Yellowberry is the result of a disease (1) that decreases N translocation to the grain and not a soil management problem.

Wheat producers cannot control climatic conditions that influence their wheat crop, but they can use soil water conservation and fertilizer management practices that will better provide the optimum soil water and NO_3-N levels to maximize yield and maintain adequate grain protein levels. Nitrogen fertilization to increase the protein level must be balanced with the amount of soil water available. The data used in this study show no apparent reason why yields, even higher than found in this study, cannot be obtained with protein levels > 13% when both soil water and soil NO_3-N can be manipulated.

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